(2)

AD-A250 227

Final Technical Report

DTIC
ELECTE
MAY 1 9 1992
S C D

Contract No. N00014-90-J-1746

for the period 4/23/90 - 12/31/91

Asymptotic and Numerical Methods in Applied Wave Propagation

Prepared for

Office of Naval Research

G. A. Kriegsmann (jp)

Gregory A. Kriegsmann

Professor of Mathematics

Department of Mathematics

New Jersey Institute of Technology

Newark, NJ 07102

(201) 596-3427

E. L. Reiss (jp)

Edward L. Reiss

Professor of Applied Mathematics

Department of Engineering Sciences and

Applied Mathematics

The Technological Institute

Northwestern University

Evanston, IL 60208

(708)491-3345

The initial thrust of our research program was to study the propagation of acoustic waves from a time periodic point source in an ocean whose properties vary slowly with range, and which rests on an elastic bottom (whose properties may also vary slowly with range). The motivations for these investigations were to study the propagation of sound in realistic ocean environments and to specifically understand the physics of mode cut-off. In this important situation it is imperative to know the amount of energy lost to the ocean bottom and the amount converted into the reflected modes. The detailed knowledge of the reflected acoustic wave is important in target acquisition and determination, i.e., in inverse problems. Our research program evolved over the last part of the contract period to address and study certain types of inverse problems which may prove useful target determination and acquisition.

Appendix A contains a bibliography of papers published, submitted for publication, or in preparation that have been supported by this contract. Reprints and preprints of some of these papers are enclosed with this report.

We now summarize our results.

Propagation in Range Dependent Occurs.

1. We have considered the model problem of an ocean of non-uniform depth overlying a semi-infinite acoustic material. This acoustic material is an approximation to the elastic bottom of the ocean. The depth of the interface is a slowly varying function of the range and in addition, the sound velocities in the ocean and acoustic bottom are functions of the depth coordinate z, and slowly varying functions of the range. The scattering of a propagating mode for this problem was previously considered by Pierce [1] and others. In Pierce's analysis, it was assumed that the densities and sound speeds in the ocean and in the acoustic bottom are of the same magnitude, and the length scale associated with changes in the interface is large in

comparison with a typical acoustic wavelength. The results showed that the energy originally propagating in the upper acoustic layer can at a critical depth, leak into the acoustic bottom and be lost by radiation. In addition, it was shown that no reflected wave is generated in the ocean. We have studied this problem in different limits. First, we have assumed that the density in the bottom is much larger than that in the ocean, while the sound speeds are of the same order. In this limit we find that there can be a substantial reflected wave in the ocean, as well as a transmitted wave radiated into the bottom. Secondly, we have assumed that both the density and sound speed in the bottom are large in comparison with the values in the ocean. We find that the results for this case are similar with our first case. We feel that these models are physically more realistic in that they better model the true astic bottom. A preprint of our paper describing these results is attached to this report.

Inverse Scattering

2. The field of inverse scattering is concerned with the determination of an object's shape from scattering data. In a fundamental paper [2] Keller used the theory of geometrical optics to formulate and to partially solve this problem for convex objects. Specifically, he showed that the amplitude of the scattered field in the backscattered direction was related to the curvature of the obstacle at a unique specular point in two dimensions, and to the Gaussian curvature in three dimensions. In the former case he was able to determine the obstacle's shape to within a rigid translation. He obtained similar results for the later case when the object was a surface of revolution and the incident wave propagated along the axis of rotation. In general, he observed that the problem became equivalent to Minkowski's problem whose solution required solving a nonlinear partial differential equation. Weiss used Keller's results on several specific examples and studied the effects of noisy

data and of relaxing the convexity restrictions [3]. Neither author used the phase information from the geometrical optics approximation.

We have developed a simple algorithm which uses the phase information from the geometrical optics limit to construct the shape of a convex object. Essentially, the phase in the back scattered direction determines the equation of the tangent plane at the unique, but unknown, specular point. This plane depends upon the two spherical angles θ and ϕ, which describe the incident wave direction. By observing that the tangent plane envelopes the obstacle as θ and ϕ are varied, we have obtained an explicit formula for the equation of the surface in terms of the measured scattered phase. The detailed description of this algorithm and examples are contained in the attached preprint.

In [4] a direct method and a simple inverse method, which can be used to determine the velocity profile of a shear layer, are presented. Specifically, an infinite acoustic medium, with constant density and sound speed, containing a free shear layer of infinite extent, is considered. The free shear layer is probed with a two-dimensional plane wave, incident on the layer from outside, and it is assumed that the maxiumum Mach numbers for the flows in the shear layers are small, e.g. $M = 10^{-3}$ to 10^{-4} are typical values for oceanic shear layers. Then, the method of matched asymptotic expansions is employed to obtain an asymptotic expansion of the solution of the direct scattering problem as $M \to 0$ that is uniformly valid in the dimensionless wave number k and the angle α of the incident plane wave. It is found that the reflection coefficient of the scattered wave is proportional to the Fourier transform of the velocity profile of the free shear layer. The transform is inverted to obtain an asymptotic approximation of the solution of the inverse scattering problem. That is, given an incident plane wave and measurements of the

reflected wave for a sequence of frequencies, approximations of the thickness and flow velocity distribution of the layer are determined. These results may be useful for studies that use acoustic exploration methods to determine oceanographic properties. We intend to continue this work on inverse scattering.

References

1. Pierce, A. D., "Guided Mode Disappearance During Upslope Propagation in Variable Depth Shallow Water Overlaying a Fluid Bottom", J. Acoust. Soc. Am. 72, (1985) pp. 523-531.
2. Keller, J. B., "The Inverse Scattering Problem in Geometrical Optics and the Design of Reflectors", IRE Trans. Ant. Prop., AP-7 (1959), pp. 146-149.
3. Weiss, M. R., "Inverse Scattering in the Geometric-Optics Limit", Journ. Opt. Soc. Am., 58 (1968), pp. 1524-1528.
4. Ahluwalia, D. J., Kriegsmann, G. A., and Reiss, E. L., "Direct and Inverse Scattering of Acoustic Waves by Low-Speed Free Shear Layers", J. Acoust. Soc. of Am. 88 (1990), pp. 1596-1602.

Appendix A. Papers published and submitted

1. D. S. Ahluwalia, G. A. Kriegsmann, and E. L. Reiss, "Direct and Inverse Scattering of Acoustic Waves by Low Speed Free Shear Layers", J. Acoust. Soc. of Am., 88 (1990), pp. 1596-1602.

2. G. A. Kriegsmann, "Acoustic Target Reconstruction Using Geometrical Optics Phase Information", I.M.A. Journal of Applied Mathematics, in press.

3. W. L. Kath, G. A. Kriegsmann, A. A. Minzoni, and E. L. Reiss, "Energy Leakage and Reflection in Underwater Upslope, Acoustic Propagation, J. Acoust. Soc. of Am., submitted.